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14. ABSTRACT

The attenuation of vertical impact forces in helicopter mishaps is one of the prime factors in determining survivability. Within the cockpit, energy-absorbing crewseats have made significant improvements in helicopter crash survival. The first crashworthy crewseats used fixed-load energy absorbers (EA's) to limit the load on the occupant's spine. These EA's were not adjustable and stroked at a factory-established, constant load through their entire operating range. Energy absorbers (also known as energy attenuators or load limiters) were then developed with a provision for manually adjusting the load so that a wide range of occupants would have equal protection in a crash. An EA load is selected that is proportional to the occupant's weight so that each occupant will experience similar acceleration and use similar stroking space in a crash. This technology was applied in programs to retrofit new seats into the U.S. Navy's CH-53 Sea Stallion and SH-3 Sea King aircraft. Work is currently underway to produce the next-generation energy absorber. The improved EA must be able to perform several functions. It must exhibit a load-deflection curve that produces the most efficient operation within the limits of human tolerance and within the limited vertical space available in military helicopters. It must also provide equal protection for the entire aircrew population, from the smallest female to the largest male. The efforts to date have produced very promising results. This paper summarizes the development of the advanced energy absorber stroking profile and the seat dynamic test results.

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DEVELOPMENT OF AN ADVANCED ENERGY ABSORBER

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ABSTRACT

The attenuation of vertical impact forces in helicopter mishaps is one of the prime factors in determining survivability. Within the cockpit, energy-absorbing crewseats have made significant improvements in helicopter crash survival. The first crashworthy crewseats used fixed-load energy absorbers (EA's) to limit the load on the occupant's spine. These EA's were not adjustable and stroked at a factory-established, constant load throughout their entire operating range

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INTRODUCTION

The use of energy-attenuating crew seats is intended to reduce the loads and accelerations experienced by the occupant during a crash to tolerable levels. In most seat designs, a movable seat bucket is attached to the helicopter structure via an energy absorbing device. During the crash sequence, the seat bucket moves (strokes) downward in relation to the floor.

First-generation energy absorbing seats stroked at a fixed load throughout the entire length of stroke. The energy absorber's load was optimized for the 50th-percentile male occupant, and therefore it did not provide optimum crash protection for the entire aircrew population. The next generation of energy absorbers had provisions to allow the EA stroking load to be manually adjusted by the occupant for his/her mass.

For a rigid mass, a constant-load energy absorber provides the theoretically highest amount of energy absorption for a given displacement at constant acceleration. However, the human body does not dynamically respond as a rigid mass, and providing a constant load to the seat bucket does not produce constant occupant acceleration and/or spinal loading. Instead, the constant-load EA produces a dynamic overshoot situation, and the EA load must be set low so that the peak spinal loading during the overshoot does not exceed injurious levels. This overshoot typically occurs during the first portion of the stroking cycle, leaving room to improve the stroking efficiency, as shown in Figure 1.

The EA system developed during this program addresses several issues. Computer modeling was conducted to determine the

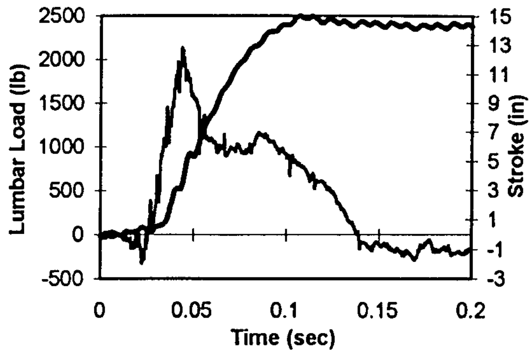

Figure 1.
Typical lumbar load and seat stroke for fixed-load energy absorbing seat.

optimum energy absorber stroking profile for a broad range of crash scenarios and occupant sizes. An energy absorber was developed which would provide the desired load versus stroke characteristics. A series of seat dynamic tests were conducted to compare the performance of the new energy absorber to the FLEA (Fixed Load Energy Absorber). Finally, results from these tests were used to refine the stroking profile.

ENERGY ABSORBER STROKING PROFILE

Notched-profile EA's (Figure 2) were studied during the late 1960's and early 1970's utilizing a simple computer model (Reference 1). Several factors hindered further development of the notched profile, including lack of a sufficiently sophisticated analysis tool to aid the EA design process.

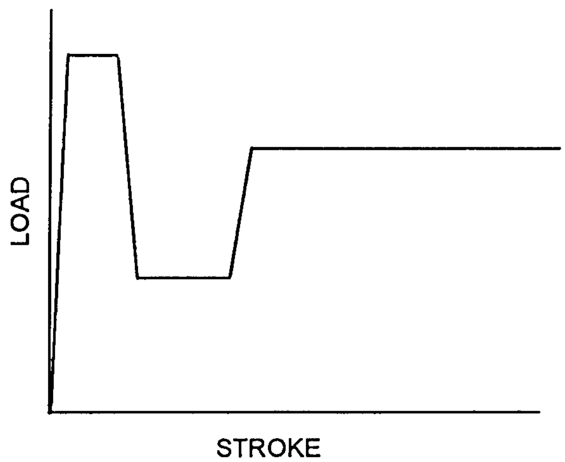

Figure 2.
Schematic load versus stroke profile for a notched load energy absorber.

The premise of the notched EA load profile was to compensate for the dynamic response of the occupant, and thus be able to apply a higher load after the peak loads on the occupant had passed. By pre-compressing the spine, the average stroking load can be raised, thereby reducing the length of stroke required to attenuate the impact energy. The benefit would be shorter stroking distances for a given tolerance. An alternate approach would be to maintain the same stroking distance as a constant load EA, but provide an overall "softer ride" for the occupant.

For this program, the selected approach was to reduce the stroke as much as possible without exceeding human tolerance. This approach minimizes the potential of the seat "bottoming out" during severe crashes. A reduced stroking distance is also favorable for the design of some new helicopters, where overall size must be minimized.

Computational Results

Computational model Seat Occupant/Model-Light Aircraft (SOM-LA) (Reference 2) was used exclusively for the analysis. The model was modified to allow evaluation of complex EA profiles, and to simplify input and output for the parametric study. Over 4,000 cases were evaluated to select the optimum stroking profile. Some of the parameters evaluated included the occupant size, the seat stroking mass, and multiple crash pulses/impact attitudes. Some limitations were placed on the complexity of the EA profiles realizing design/manufacturing limitations. The intent of the modeling was not just to find the ideal EA profile, but to find an EA profile that could be fabricated within the realm of reasonable EA design characteristics.

The final selected profile shape is represented in Figure 3. The profile contains three elements. The first element is an initial spike load, which can be varied proportionally to the total stroking mass. The analysis indicated the spike load should have a high onset rate and be of short duration. The spike load is followed by a low-magnitude notch load. The notch load reduces the dynamic overshoot phenomena associated with constant-load EA's. The final portion of the profile is a hold load, whose magnitude is varied proportionally to the total stroking mass. The energy absorber designed for this profile is referred to as a Variable-Profile Energy Absorber (VPEA).

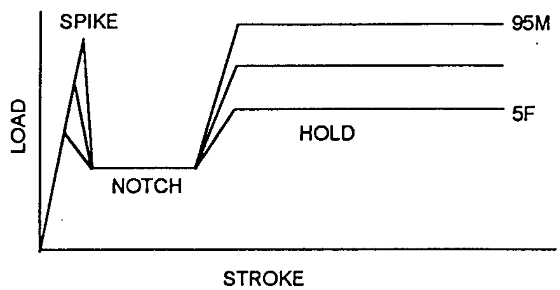

Figure 3.
Schematic of variable profile energy absorber load versus stroke.

The VPEA hold load is significantly higher than the stroking load currently utilized by FLEA's. For a severe crash, such as one requiring 12 in. stroking distance, the VPEA will absorb approximately 28 percent more energy than the FLEA. However, the FLEA will absorb more energy than the VPEA during the first 4.5 in. of stroke due to the relatively low notch load.

PERFORMANCE

Performance Criterion

Two criterion were selected for the evaluation of a seat equipped with the newly developed VPEA. These were the total amount of seat stroke, and the probability of minimizing injury. As noted previously, the objective of this program was to minimize seat stroke without increasing the injury probability of current FLEA-equipped seating systems.

There are several methods of evaluating the injury probability. These include the Eiband criteria, the dynamic response index (DRI), and the peak measured lumbar spinal load. Both the Eiband criteria and DRI are based on the measured acceleration at the seat pan, and do not take into account such factors as the seat pan cushion response or the occupant's size. On the other hand, the measured lumbar load provides a direct measurement of spinal injury potential. Since the primary objective of the seat energy absorber is to prevent spinal injury, the spinal load criterion was selected for the evaluation of the VPEA performance. During this program, lumbar tolerances were selected for the 5th-percentile female through the 95th-percentile male, as shown in Table 1. A more thorough discussion of the lumbar load tolerance selection is presented in Reference 3.

Table 1.
Selected Lumbar Tolerances for Naval Aviators

Occupant Size (percentile)	Lumbar Load Tolerance (lb)
5th Female	1,281
50th Female	1,610
50th Male	2,065
95th Male	2,534

Seat Dynamic Test Matrix

To determine the effectiveness of the VPEA performance, all seat dynamic tests were conducted with a baseline FLEA-equipped seat, and a VPEA-equipped seat. The Simula-produced UH-60 Black Hawk seat was selected as the test seat. The Black Hawk seat bucket strokes on a pair of guide tubes inclined at four degrees from the vertical axis. Linear roller bearings are utilized to minimize frictional losses as the seat strokes. The Black Hawk seat has been involved in several field crashes and has exhibited exceptional occupant spinal protection characteristics (Reference 4).

A total of 8 test series consisting of 18 tests in total were selected for the evaluation as shown in Table 2. All but Test Series 6 were conducted with a pure vertical seat orientation. The pure vertical pulse was selected for the majority of the tests as it provides the most direct evaluation of EA performance. The test pulses ranged from a hard landing (Series 2) to a high onset rate (Series 4) to simulate water impact. A landing gear pulse with a 6-G initial plateau followed by a 48-G triangle pulse was also included (Series 5). Test Series 1 through 6 used a 50th-percentile male manikin, Series 7 used a 5th-percentile female manikin, and Series 8 used a 95th-percentile male manikin. All the tests have been completed.

Test Results

The test results are summarized in Table 3. In general, the VPEA provided a substantial performance improvement when compared to the FLEA. For the high-energy pure vertical tests with the 50th percentile manikin (Test Series 1, 3, 4, and 5) the VPEA-equipped seat stroking distance was reduced by an average of 24.4 percent compared to the FLEA-equipped seat. In most cases, lumbar loads are either near the tolerance limit (2,065 lb) or are comparable to the FLEA-equipped seat.

As expected for the low-magnitude test pulse (Series 2), the VPEA stroking distance was slightly longer than the FLEA. The intent of this test was to show that spinal injury would not be likely during minor impacts. The measured spinal load was higher than the FLEA, but the magnitude (1,538 lb) was still lower than the tolerance level.

Table 2.
Seat dynamic test matrix

Test Series	Occupant Size (percentile)	Velocity Change (fps)	Onset Rate (G/sec)	Peak Accl. (G)	Other Variable	FLEA Tests (qty)	VPEA Tests (qty)
1	50th Male	42	1,150	48		2	2
2	50th Male	21	575	20		1	1
3	50th Male	34	1,150	40		1	1
4	50th Male	42	2,000	48		1	1
5	50th Male	50	N/A	48	Landing gear pulse	1	1
6	50th Male	50	1,150	48	30 deg. pitch	1	1
7	5th Female	42	1,150	48		1	1
8	95th Male	42	1,150	48		1	1

For the landing gear simulation pulse (Series 5), the FLEA had an exceptionally low lumbar load (1,185 lb). It is not known if this was a testing anomaly, or if the landing gear pulse indirectly provided a notched EA effect by pre-loading the spine. Additional tests and/or modeling would be needed to determine the reason for this low lumbar load. The VPEA produced a lumbar load of 1,998 lb and reduced the stroking distance by 22.9 pct.

For the 30-degree pitch down test (Series 6), both the FLEA and VPEA produced unacceptably high lumbar loads (3,201 and 3,443 lb respectively). It is hypothesized that the forward loading component causes the manikin to load into the shoulder harness, thereby producing an additional down load due to the restraint geometry. This high loading is of concern since most helicopter crashes occur with some longitudinal component. Additional tests will be required to verify these results.

For the light occupant test, the VPEA lumbar load was approximately 7 percent below the selected tolerance. For the heavy occupant test, the VPEA lumbar load was about 36 percent under tolerance. The results of these two tests would indicate that the VPEA adjustment range needs to be expanded further (lower load for the light occupant, higher load for the heavy occupant). However, more tests will be required to minimize the effect of normal test scatter. The stroking distance of the VPEA cannot be fairly compared to the FLEA for these two tests, as the FLEA is tuned for the 50th-percentile male occupant.

CONCLUSIONS

The performance of the Advanced Energy Absorber has been very impressive. There has been significant reduction in seat stroke while maintaining comparable lumbar loads. In some cases, both the lumbar load and seat stroke have been reduced.

Table 3.
Summary of seat dynamic test results

Test Series	Occupant Size (percentile)	Peak Lumbar Load (lb) FLEA	Peak Lumbar Load (lb) VPEA	Seat Stroke (in.) FLEA	Seat Stroke (in.) VPEA	Stroke Change (pct)
1a	50th Male	1,745	1,818	14.0	10.5	-25.0
1b	50th Male	1,979	2,108	14.9	10.2	-31.5
2	50th Male	1,284	1,538	3.3	3.6	+9.1
3	50th Male	2,147	1,878	9.7	7.1	-26.8
4	50th Male	2,164	2,068	15.0	12.6	-16.0
5	50th Male	1,185	1,998	14.4	11.1	-22.9
6	50th Male	3,201	3,443	10.9	10.3	-5.5
7	5th Fem.	1,535	1,192	7.8	11.4	+46.2
8	95th Male	1,320	1,617	12.9	9.5	-26.4

Reduced stroke can provide more flexibility during the aircraft design and/or expand the survivable crash envelope. Other benefits of reduced stroke include a reduced occupant strike envelope, and facilitating occupant egress.

Work that remains to be done includes repeating several dynamic test conditions, performing operational testing, and environmentally hardening the system. In terms of performance improvements, reducing the high lumbar loads in certain mishap scenarios and expanding the adjustment range are areas being investigated. It should be possible to overcome these issues as the system is refined in the next development stage.

REFERENCES

1. Carr, R. W., and Phillips, N. S., Definition of Design Criteria for Energy Absorption Systems, NADC-AC-7010. June 1970.

2. Laananen, D. H., Bolukbasi, A. O., Coltman, J. W., Computer Simulation of an Aircraft Seat and Occupant in a Crash Environment Volume I - Technical Report, TR-82401, Simula Inc., Tempe, Arizona, DOT/FAA/CT-82/33-1. Federal Aviation Technical Center, Atlantic City Airport, NJ, March 1983.

3. Labun, L. C., Rapaport, M., A Third Generation Energy Absorber for Crash Attenuating Helicopter Seating, Presented at the American Helicopter Society 50th Annual Forum, Washington, DC, May 1994.

4. Shanahan, D. F., Black Hawk Crew Seats: A Comparison of Two Designs, USAARL LR 92-1-4-1. November 1991.

BIOGRAPHIES

Marvin K. Richards is a Staff Engineer for the Safety Technology group at Simula Technologies, Inc., Phoenix, Arizona. Mr. Richards is responsible for all phases of new safety system product development from initial concept and proposal through detailed design. In addition to other programs, he is currently serving as the Project Engineer for this advanced energy absorber development program. Mr. Richards has been at Simula for 13 years, and holds five U. S. patents. He received a B.A. in Mechanical Engineering from Arizona State University in 1981.

Roger Podob is an Aerospace Engineer for the Naval Air Warfare Center, Aircraft Division, Patuxent River, Maryland. Mr. Podob provides a number of functions, including crashworthy analyses, engineering services for improving existing and future safety equipment, as well as consolidation and analysis of safety center mishap data. He also manages the Aircraft Crash Survivability Lab at Patuxent River. He is the Navy's Project Engineer for this advanced energy absorber. He received his B.S. in Aerospace Engineering and his M.S. in Aeronautics and Astronautics from Polytechnic University in 1989 and 1993, respectively.

Attachment B1

AUTHORS' QUESTIONNAIRE
(To be sent IMMEDIATELY)

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on

FLIGHT IN A HOSTILE ENVIRONMENT

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Attachment B2

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PLEASE LIST NAMES OF ALL AUTHORS (starting with the Lead Author): **PAPER No: 21**

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- Marvin Richards

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BIOGRAPHY OF LEAD AUTHOR AND ALL POSSIBLE SPEAKERS:

Since the biographies are to be read by the **Session Chairman** when introducing the speaker to the audience, it would be appreciated if you would let us have in advance (in written form and preferably typed of approximately 100 words) a one minute speech on the background and experience of each speaker.

Roger Podob is an Aerospace Engineer for the Naval Air Warfare Center, Aircraft Division, in Patuxent River, Maryland. Mr. Podob provides a number of functions, including crashworthy analyses and engineering services for improving existing and future safety equipment, as well as consolidation and analysis of safety center mishap data. He also manages the Aircraft Crash Survivability Lab at Patuxent River. He is the Navy's Project Engineer for this advanced energy absorber. He received his Bachelor of Science degree in Aerospace Engineering and his Master of Science degree in Aeronautics and Astronautics from Polytechnic University in New York, 1989 and 1993, respectively.

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